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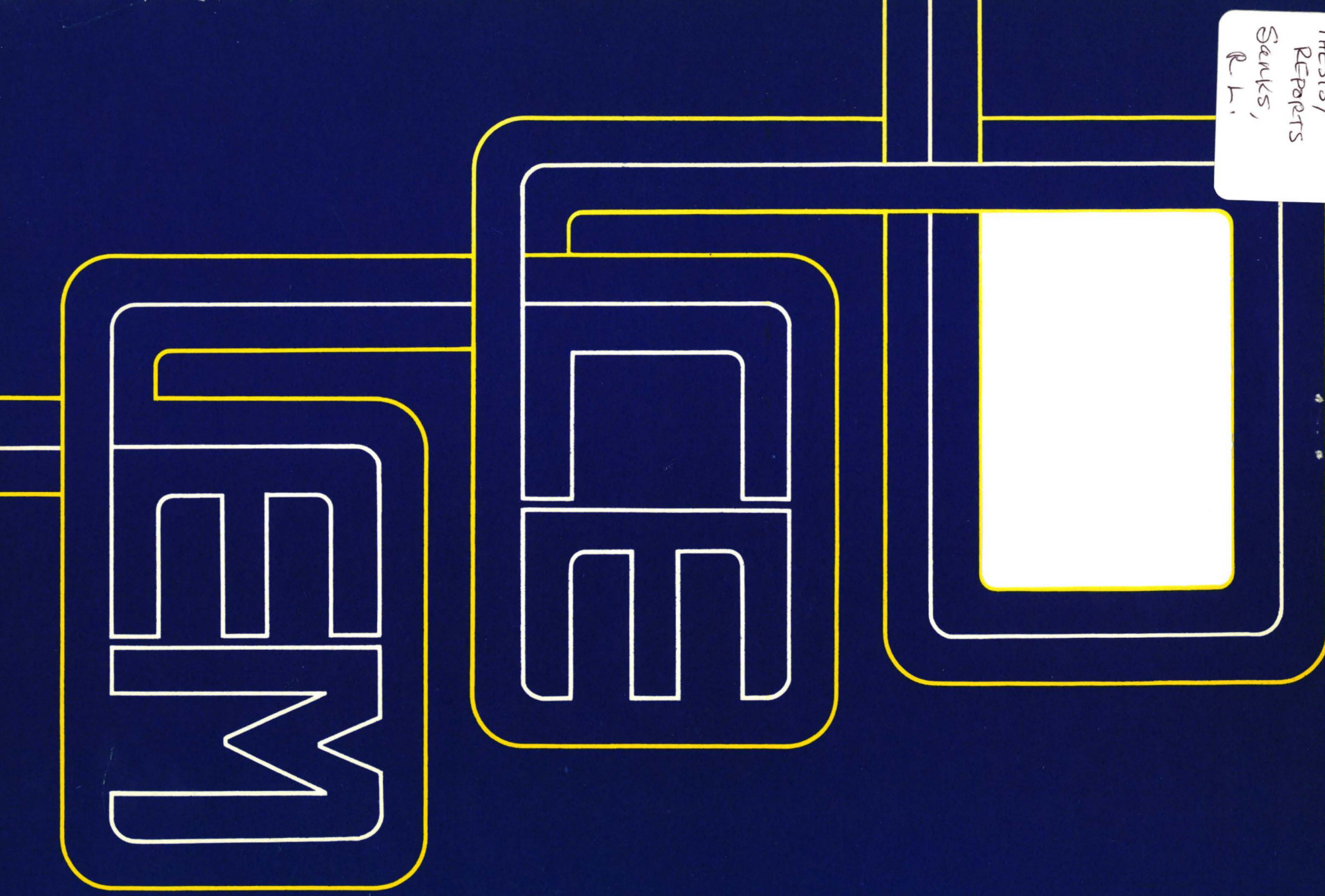

Department of Civil Engineering & Engineering Mechanics Montana State University Bozeman

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FINAL REPORT

on

LIQUID AND SOLID WASTE DISPOSAL IN U. S. FOREST LANDS FS-INT GRANT NO. 7

by

R.L. Sanks and K. L. Temple

April, 1975

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to

Forestry Sciences Laboratory
Intermountain Forest and Range Experiment Station
Forest Engineering Research
Bozeman, Montana

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CHAPTER 1
INTRODUCTION

The burgeoning use of U.S. Forest Service lands, particularly for recreation, has created problems of increasing severity in disposal of liquid and solid wastes. Reawakened public awareness of pollution and recently stiffened government regulations have highlighted the problem. This project was intended to assess the rapidly changing technology of waste disposal, to review the state-of-the-art practice in U.S. Forest Service lands, and to delineate further research needs.

OBJECTIVES

General Objectives

The general objective is to define the problems of the disposal of liquid and solid waste on U.S. Forest Service lands and to identify high priority research needs. Specifically, the general objectives are: (1) to investigate the existing practice-of-the-art of liquid and solid waste handling in the U.S. Forest Service, (2) to analyze the problems, (3) to formulate and codify the most urgent unsolved problems, and (4) to outline a program of research.

The attack on these objectives was begun on a broad scale by an interdisciplinary team of investigators. But in January, William C. Kolzow and Charles R. Weller (engineers from the Washington, DC Office of the U.S. Forest Service) urged a specific study of the problems of Wilderness Areas. (Capitalized, Wilderness means designated U.S. Forest Service Wilderness Areas. Uncapitalized, it means any undeveloped, primitive, remote or unfrequented area.) Considerable work is underway

on other phases of the broad problem of disposal of wastes including land disposal of liquid wastes and sludge, physicochemical treatment by mobile plants, and evapo-transpiration to mention a few. These efforts should not be duplicated by repetitious study, and furthermore, the U.S. Forest Service was making in-house evaluations of much of Objective No. 1 by obtaining information on kinds, amounts, and characteristics of wastes and it was implementing studies of both well-known and exotic means of waste disposal. Hence, it seemed inappropriate to continue to attack the general objectives on a broad scale. On a narrow scale, Objective No. 3 could be partially realized because one of the most urgent unsolved problems concerns sanitation in Wilderness Areas.

Specific Objectives

Montana State University personnel agreed to apply the general objectives specifically to Wilderness Area sanitation. In general, wilderness sanitation embraces the problem of the disposal of human wastes in an innocuous manner which does not create a public health hazard and is not esthetically objectionable. It must also perforce include consideration of the droppings of wild animals and domestic stock because organisms which indicate pollution (coliform bacteria) are found in animal droppings as well as in human wastes. Moreover, organisms pathogenic to man have been identified in wild and domestic animal droppings. Public health hazards, therefore, must embrace all sources of pathogenic organisms. The special problems of Wilderness Areas lead to the following specific objectives formulated as sub-classifications of General Objectives Nos. 2 and 3.

(A) The rate of stabilization of excrement and the disappearance of coliforms and other fecal organisms should be measured.

(B) The most acceptable means for the disposal of excrement in Wilderness with respect to distance from water, kind of terrain, cover, and other conditions should be determined.

(C) The relation between use and degradation and how much continual use can be tolerated at different levels of environmental impact should be resolved.

(D) Control points should be selected on the basis of high use and "zero" use with all other conditions equal. Pollution should be measured to determine the impact of use upon land and water.

(E) Typical Wilderness Areas should be inspected to select control points. A wide range of conditions should be studied to permit interpolation of results to most Wilderness Areas.

(F) The research should be planned to enable the U.S. Forest Service to determine how to optimize the management of Wilderness Areas with respect to sanitation.

Some of these objectives might require several years of study, and obviously few could be realized within the remainder of this project period. The purpose of delineating these specific objectives was to guide the research effort for the remainder of the project. Montana State University personnel intended to pursue the specific and general objectives vigorously, and (for those which could not be completed) to obtain preliminary data which might serve both as a guide to future work and as a means for estimating the time and effort required of such future work.

A more complete description of the events leading to the emphasis upon Wilderness Area sanitation together with a detailed review of the work accomplished by April 1974 was given in the First Progress Report.

POTENTIAL FOR POLLUTION CONTROL

Comparatively little work has been done in wilderness areas and virtually nothing has been done on the disposal of human wastes in pristine environments with no man-made improvements. However, U.S. Forest Service management practices and the habits of the public unquestionably have great influence on public health hazard and on general sanitation. An adult generates nearly a pound of feces per day. At an average value of 10^8 coliform organisms per gram of wet feces, the adult excretes approximately 4×10^{10} coliform bacteria per day, which is enough to contaminate a lake half a mile in diameter and 25 feet deep with more organisms than permissible by the U.S. Public Health Service Standards (1962) for drinking water. This example illustrates the need for preventing even small amounts of feces from reaching water.

Disposal sites such as privies, latrines, or ad hoc (individual use) sites, are often found much too close to water. It would be a simple matter to locate them at appropriate distances from water in the future, but the appropriate distance must be known for various different conditions.

Latrines in the Boundary Waters Canoe Area are often close to camp sites where, presumably, campers obtain water at the edge of the lake. Again, it would be a simple matter to locate privies at an appropriate distance both from the edge of the lake and laterally from the campground to take advantage of the dilution of seepage from the latrine by lake water. This could easily be done if the appropriate distance were known. An alternative "management practice" could be practiced by the canoeists who could easily obtain water at a distance from the shore. Such distances would have to be great enough for sufficient attenuation of bacteria by predation and starvation. Again, such distances must be known.

Horse trails often skirt lakes and streams at water's edge. Such trails can often be relocated at greater distances. While bacterial survival is known to be inversely related to overland distance, there is insufficient practical knowledge to make suitable recommendations.

Little is known about the survival and transport of bacteria and virus from "cat-holes" and ground deposits, but the little that is known suggests a profound effect of burial conditions on disappearance of feces. A U.S. Forest Service publication (author and date unknown) states buried feces will decompose "in a few days." Under some conditions the statement might be true but under almost all conditions it is grossly misleading. Coliform bacteria in animal droppings are known to survive two years, so good disposal practices combined with proper site selection would have a profoundly beneficial effect in reducing public health hazard.

While other examples could be mentioned, the above illustrate ways in which management practice can cope with the problem of health hazard in the wilderness and usually in ways which involve no additional expense.

ORGANIZATION

Mr. Rulon B. Gardner, Intermountain Forest and Range Experiment Station, USFS, was the project officer. Dr. R. L. Sanks was the principal investigator.

During the first phase (prior to April, 1974) Dr. Takashi Asano (environmental engineer), Mr. Alfred Scheer (transportation engineer), Dr. J. E. Taylor (ecologist in range and forest science), Dr. Kenneth Temple (soil microbiologist), Dr. Hayden Ferguson (soil and plant specialist), and Mrs. Anne Williams (specialist in interdisciplinary studies) were faculty investigators.

Following the shift in emphasis to Wilderness Area sanitation, Dr. Kenneth Temple has acted as co-principal investigator. Dr. Gordon McFeters acted as faculty investigator, and Dr. David Stuart served as faculty advisor. Mrs. Sue Harrigan and Mr. Jimmy Jupka, graduate students in Microbiology and Civil Engineering respectively, assisted with field and laboratory work.

CHAPTER 2
HEALTH HAZARDS

INFECTIOUS DISEASES TRANSMITTED BY FECES OR URINE

The diseases in the following list occur to an appreciable extent in the United States and may be transmitted by feces or urine. Diseases which are similarly transmitted but occur rarely in this country and diseases which are strictly urban have been omitted. Otherwise the list is intended to be complete within the limits of present knowledge. It is possible that the list of viral diseases transmitted in this manner may be extended in the future. The diseases are listed alphabetically with an indication of the etiological agent and the nature of the infection. Further information is presented under other headings. For example, the occurrence and transmission details are given under the heading "Epidemiology."

1. Amoebiasis (amebiasis). A disease of the large intestine caused by a protozoan, Entamoeba (Entameba).
2. Ancyclostomiasis. Hookworm. In the U.S., due to Necator.
3. Ascariasis. A round worm, Ascaris.
4. Candidiasis. A fungus, Candida. One form of the disease is known as thrush.
5. Escherichia coli diarrhea. Some strains of this common bacterium are pathogenic.
6. Food poisoning. Fecally transmitted food poisoning is caused by Clostridium perfringens.
7. Giardiasis. Giardia, a protozoan, infects the small bowel.
8. Infectious hepatitis. A viral infection of the liver.

9. Herpangia and Versicular Stomatitis. Multiple possible infections by the Coxsackie Group A viruses.
10. Paratyphoid fevers. Enteric infections by a large number of Salmonella bacterial strains.
11. Pleurodynia. Infections of the costodiaphragmatic border by members of the Coxsackie Group B viruses.
12. Poliomyelitis. Transmission of this may be questioned. See the discussion under epidemiology.
13. Respiratory acute viral diseases. A large cateogry involving many viruses.
14. Rubella. German measles, another virus.
15. Shigellosis. A wide variety of intestinal infections by different members of the bacterial genus Shigella.
16. Strongyloidiasis. Strongyloid worms primarily infest the duodenum but also affect a variety of other tissues.
17. Tetanus. Caused by the bacterium, Clostridium tetani.
18. Typhoid fever. The most feared of the intestinal infections occurring regularly in the United States. Salmonella typhi (S. typhosa).
19. Others. Urinary tract infections are caused by several genera of bacteria.

Epidemiology

Each of the foregoing diseases is discussed briefly as to its occurrence, transmission and importance. Specific transmission methods are given where known. However, some useful generalizations can be made: (1) Fecally contaminated soil has long been recognized as a principal agent for the transmission of many bacterial and parasitic diseases and the establishment of a camping site without a careful human waste disposal system predisposes toward this method of transmission. (2) It should be noted that many bacterial, viral and protozoal disease organisms persist in soil after feces itself has disappeared or is no

longer obvious and these organisms may then come into contact with the shoes, other clothing, tents, sleeping bags or hands of persons using these sites. (3) There is a frequent tendency to neglect individual cleanliness while "roughing it" and fecally transmitted diseases are well adapted to transfer by the hands of people who do not wash well after defecation with subsequent passage of the infectious agent to food or directly to the mouth or to objects handled by others, with eventual hand to mouth transfer. (4) A carrier condition exists for many diseases and this has two implications (a) the larger the camping group the greater is the chance of disease carriers being present and (b) the more frequently a campsite is used, the greater is the chance that some of the feces deposited there may come from a carrier. Carriers are usually symptomless, healthy persons who presumably go camping as often as other people.

Transmission involving feces or urine in the following list does not imply this is the only method of transmission of that disease or even the most common method. But fecal transmission may assume greater importance in Wilderness campgrounds than in urban environments.

Amoebiasis. Occurs in warmer portions of the U.S. and sporadically in temperate zones. Spread from feces by the hands or by flies. Importance is strongly climate-determined but when outbreaks occur in temperate areas the incidence may be high for a short time. There are many healthy carriers.

Ancyclostomiasis. Limited to the south, hookworm is important where it occurs because of its debilitating effect. Transmitted by fecal contamination of soil and contact with bare feet.

Ascariasis. Limited to the south in the U.S. Fecally contaminated soil contains eggs which persist and are carried by shoes, by raw vegetables or in dust to the mouth or nose.

Escherichia coli. Pathogenic strains of E. coli cause infrequent infections of adults. The disease is transmitted to others by faulty personal toilet hygiene. Occurrence is general but sporadic.

Candidiasis. Transmitted easily from fresh feces, and there are many carriers. Infection probably is most likely if a member of the same party is infected. Occurrence is widespread and sporadic.

Food poisoning. Clostridium perfringens is a human enteric bacterium and occurs also in the intestinal tract of other animals and in soil. Under camp conditions this type of food poisoning is most likely when meat is handled with contaminated fingers and is eaten at a later meal without refrigeration. Stew held over from a previous day is a good source.

Giardiasis. A mild to severe intestinal infection. The protozoan is carried by many people and is transmitted in feces to water or by hands. The cysts are presumably resistant to chlorination.

Infectious hepatitis. Occurs typically in epidemics, with outbreaks being more common in autumn than summer in the U.S. It often affects school age children and young adults, and it may be a mild disease, but it can be serious or even fatal. It is transmitted by contact with feces.

Herpangia and Vesicular Stomatitis. The Coxsackie Group A viruses usually attack children under ten, rarely adults. Carriers are numerous. It is transmitted by contact with fresh feces. Flies are known to carry the viruses but their role in transmission is uncertain.

Paratyphoid fevers. The Salmonellae which cause paratyphoid infections are carried by many people. Transmission is by many direct and indirect means as the organisms persist in soil, water, food and on

inanimate objects and are also carried by flies. In the presence of an acute infection, the disease is apt to spread unless strict sanitary measures are adopted. The disease is not usually serious but it can be on rare occasions. It is widespread and sporadic.

Pleurodynia. The Coxsackie Group B viruses are carried by many people. They are apt to spread through a group if an infection breaks out. The transmission is sometimes from contact with fresh feces. Flies and mosquitoes carry the viruses but their implication in disease transmission is not established. The virus persists in sewage. The disease is infrequent but outbreaks occur among older children and young adults in the summer and fall.

Poliomyelitis. A serious disease but limited because of the general adoption of immunization. In recent years, the immunization rate has dropped dangerously. The transmission has never been satisfactorily determined but the virus occurs in feces and the relative importance of feces to other materials in transmission is uncertain.

Acute respiratory viral diseases. Among the many viruses that infect the respiratory tract, the enteroviruses and the adenoviruses are known to be discharged in feces and this may be a route of transmission. The occurrence is greatest during fall or winter camping where victims have been previously infected but it does occur in epidemic form in children's summer camps. It is primarily a children's disease in its more severe forms.

Rubella. German measles virus is present in feces and in urine but susceptible persons in close contact with a disease will probably contract it by other means regardless of waste disposal methods.

Shigellosis. Shigellae are carried by man and other animals. There are many bacteria in this genus which have different virulence.

The transmission is from feces of sick people or from healthy carriers, with water, food, the hands and flies all being involved. The infection may be acutely disabling but is self-limited in temperate climates.

Strongyloidiasis. The occurrence and transmission are very similar to that of hookworm.

Tetanus. Clostridium tetani inhabits the intestinal tract of man and other animals as well as certain soils. It is more common in horse feces than in human feces and for this reason wounds contaminated by horse feces or soil used by pack animals are particularly dangerous. This might have implications for the placing of pack animals in relation to a camp.

Typhoid fever. Salmonella typhi is carried by a small percent of the healthy population and excreted in feces and in urine. It is acquired by fecal contamination of food or water, or by the transfer from hands to food. Starchy foods and milk are particularly good vehicles. Without antibiotics, there is a ten percent fatality.

Urinary infections. Most of these develop from organisms already present and are not in the contagious category. Nevertheless, urine from infected individuals should not enter drinking water supplies. If this seems self-evident, it may be worth pointing out that there are observed instances of urination in stream beds where hiking trails are close to the stream.

Likelihood of Infection

Inasmuch as nineteen types of infectious diseases have been identified in this section, it may be helpful to make some general summary observations about their expected importance to users of the outdoors. Intestinal infections occur commonly and are often found among vacationers using motels, commercial campsites and trailer parks and in

state or federal camp sites. These are actual active cases, not carriers. Occurrences are bound to take place among hikers and canoeists. Most of these infections will be self-limiting even under fairly primitive camping conditions and without medication but on occasion they may be serious. The only truly dangerous disease among these which occurs in the U.S., typhoid fever, has recently increased in occurrence. As Wilderness Areas become more crowded, instances of these enteric infections will increase. Both salmonellosis and shigellosis fall in this category.

Those diseases which typically occur in epidemic form may occasionally infect campers. This is particularly true of the diseases affecting primarily camping-age children and young adults. Infectious hepatitis is possibly the most likely but Coxsackie virus diseases are also a real possibility, especially among groups of younger campers.

The other diseases listed should be rare among campers but on a statistical basis can be expected eventually. Some of these will not be recognized as being contracted during the camping trip.

The parasitic diseases characteristic of the southern states or of the southeast will be geographically limited but should be of concern in those areas.

Food poisoning does occur among campers but the causative agent is usually not diagnosed. Of the four common types, the one described here, due to C. perfringens, will surely occur among some campers but is minimized by the use of modern light weight camp foods. It will occur most frequently in larger parties which remain in one campsite for at least two days and which also carry fresh meat.

An example of a possible infection chain may be instructive to illustrate the more infrequent diseases. Suppose there are sporadic

outbreaks of acute respiratory disease due to viruses in one particular summer, as there sometimes are. Suppose also these occur in summer camps, as they do. Suppose further that one camp has been exposed to such an infection, perhaps an adenovirus, but that no one shows any symptoms because there is a long incubation period (up to two weeks). This would allow an exposed group of apparently healthy children to leave the summer camp for a hiking or canoeing trip and for the disease to break out after a few days in the Wilderness. The group was probably infected originally by the droplet route from oral or nasal discharges. However, at their campsite they deposit feces which carry large numbers of the virus and fecal contamination is a possible transfer route for this disease. As this party leaves a campsite, another party promptly moves in, and accidental contact with feces could transfer the infection to the new group. In this type of disease, the method of disposal of feces would be critical.

For practically all of the diseases considered in this section, the incidence is low but sanitary preventive measures are needed and can markedly reduce the occurrence of outbreaks. For the parasitic diseases, incidence is high in the geographic areas in which they occur but can be made negligible with proper precautions.

SURVIVAL OF PATHOGENS FROM URINE AND FECES

Epidemiological studies are usually conducted in connection with major outbreaks of disease in urban populations or for diseases which have a high incidence rate in rural populations and which are both economically and medically important. For this reason, there is little solid data that is applicable with certainty to the Wilderness situation. Some generalizations about survival of pathogens are definitely pertinent.

It is a very rough generalization that many, probably most, pathogens disappear fairly quickly when deposited in soil or water and that

others which do live in such environments lose their ability to invade and cause disease. The exceptions to this are both numerous and important. In the preceding list under the heading of "Epidemiology," fresh feces was stated to be a possible transmission route whenever viable organisms are found in feces. But it is not known how long the organisms can remain virulent. Epidemics of typhoid fever have led to several demonstrations that the typhoid bacterium can withstand months of exposure. One typhoid epidemic in the U.S. occurred during a spring snow melt when organisms from contaminated cloths that had lain in the snow for months entered a municipal drinking water supply. Salmonella and Shigella infections are water borne precisely because of the ability of the organisms to remain virulent and alive outside the body. Bacterial spores are even more resistant, persisting for years in the soil. In addition, the spore-forming Clostridia grow in some soils as well as in foods. Tetanus is the disease in this category which is most likely to be contracted from a soil or a soil-feces source. Perfringens food poisoning can arise from soil borne Clostridia but is more apt to result from fecal contamination of food via the hands. Viruses have often been recovered from soil and water and from sewage at various stages of treatment. There are ongoing studies in the movement of viruses through land fills and in the soil disposal of sewage. As yet there is a dearth of solid information about the importance of virus survival. The parasitic diseases in our list are normally persistent in soil and have a high incidence in warm zones because soil plays a customary role in the survival of cysts and in their case soil transfer is the usual route rather than an occasional one.

Transmission involving fecal routes is relatively minor for several of the diseases discussed here. Under most conditions of human living, the organism passes from one person to another by some other form of contact. This is true of the respiratory infections, and other viral diseases, but here we are investigating the possibility of transfer

under specific unusual living conditions. The fecal-water and fecal-soil routes may consequently assume much greater importance for campers.

HEALTH HAZARD AND ESTHETICS

The disposal of human wastes in national parks is sufficiently serious to be the topic of a national meeting in December 1974. Hopefully, Wilderness areas will not get the visitor use equal to that of national parks. Still, the esthetic aspects of decomposition of feces is a problem in a few specialized localities at the present time, viz. some mountain climbing sites and some rivers. It may become serious in other areas due to a combination of high use and a low decomposition rate due to soil or climate factors. There is a natural tendency to equate the potential danger of fecally transmitted disease and the esthetic aspects of fecal persistence but this is without substantiation. Consequently, it is necessary to determine fecal decomposition rates in different soil-vegetation-climate locations and to accompany this by an actual measurement of the persistence or disappearance of pathogens. In order to avoid the use of actual pathogens in Wilderness areas, one might study harmless but similar enteric bacteria or viruses as model organisms. One could also study viruses which will always be present in many fecal specimens.

Disposal Methods for Feces

Surface. People in many parts of the earth still deposit feces and urine directly on the soil surface. Epidemiological studies clearly damn this practice and show that there is a direct cause and effect relationship between the lack of sanitary waste disposal and the high incidence of fecally transmitted infectious disease in such countries. The route of transmission in such localities frequently involves food grown on such soil, e.g. raw vegetables. Waterways in India are so thoroughly contaminated with Salmonella that shipments of frogs to

restaurants in the U.S. (the major source of frog legs) are often rejected by U.S. inspectors. The World Health Organization finds that efforts at disease reduction in undeveloped nations are temporary unless there is an eventual improvement in human waste disposal. Among domestic animals and human alike, the sanitary disposal of excreta is one of the most effective ways of lowering the morbidity rate. There is undoubtedly a point at which the use of Wilderness will begin to reveal some of these problems.

Deposition of feces on the surface but covered by a rock or leaves is not much better aside from visual appearance. Such deposits may be washed out by rain into drinking supplies or onto campgrounds. Feces covered by leaves may be all the more dangerous because they are not seen. Rocks may slow the rate of decomposition. Nevertheless, this may be the only available method in some rock climbing areas (other than surface deposition).

The rate of decomposition of feces and the rate of disappearance of pathogens are two different matters. Each will vary tremendously with the amount of precipitation, the temperature, the degree of contact with soil, the soil type, insect activity and possibly other factors. These should be quantitatively investigated.

Thin soil covering. This is a common method of disposal and one that is frequently recommended to campers and hikers. It meets the esthetic objections and has the advantage of promoting decomposition rates and also the rate of removal of pathogens. Covering with a thin soil layer ensures good contact with soil on all sides with consequent early growth of saprophytic bacteria and molds into the fecal mass, and free penetration by small soil animals such as insect larvae, mature insects and other arthropods. The result is the fastest possible rate of humification of the feces. The initial moisture content of feces allows decomposition to proceed even under very dry weather conditions

and the fertilizer effect promotes an outburst of microbial growth in the immediate soil vicinity. The effect is cyclic, the enhanced microbial growth in soil in turn accelerating microbial movement into the fecal mass. All of these are positive factors. In addition, thin burial usually provides the optimum temperature for decomposition and retards drying. On the other hand, there are some disadvantages. Shallow burial provides minimum protection against physical contact by subsequent campsite users. It does not necessarily prevent the washing by rain into water supplies or onto campsites. It promotes the colonization by flies and leaves open the possibility that they may carry pathogens to food. The persistence of pathogenic organisms under this method of disposal is unknown and needs quantitative study.

Latrines and pit toilets. These are also traditional methods, once widely recommended and used but less so today. A properly constructed and used trench can avoid most of the objections of thin or shallow burial. If fecal material is covered immediately, the fly problem is eliminated. Aside from the fact that many people will not take the trouble to build a good latrine, the principal sanitary objection is that deeper burial results in a slower decomposition rate and in very loose soils may not prevent movement of pathogens into water channels. There is also the problem of mechanical disturbance of the surface near a frequently used campsite.

Urine Disposal

Urinary tract infections are often chronic and mild, erupting occasionally into acute cases. Most such infections are bacterial and due to several genera. Little is known about the transmission except that a urinary tract infection leads to large numbers of bacteria excreted in the urine.

Disposal of urine directly onto soil would presumably not constitute a hazard except under very unusual coincidental conditions. The

expected danger would be from disposal into a water supply. It is known that some professional guides allow their client to urinate directly into streams that are used as water supplies, and this occurs principally where trails are in a stream bed, a common situation in steep country. This also happens with pack stock and urination as well as defecation by pack animals around mountain lakes is often ignored.

PIT TOILETS, LATRINES, AND DEEP BURIAL

If the intensity of use becomes too great for the assimilation and degradation of fecal material, or the hazard of uncovering a pathogenic burial in digging for a new shallow burial, or where the population is too great or the flora too sparse for privacy, some type of centralized toilet facility is the only recourse which combines continued use with public safety. The pit toilet or latrine is the most commonly constructed facility and it has been used since antiquity. But almost nothing is known about its biochemical mechanisms, survival rates of bacteria and viruses, the leaching of microorganisms into the surrounding soil, nor the length of time required for feces to decompose into innocuous substances. An unconfirmed report of a privy, dug up accidentally by a bulldozer after more than 20 years of non-use and which appeared to be "fresh" suggests that mechanisms which degrade small samples do not occur at privies.

Small samples from individual use sites are rapidly attacked by soil microorganisms which occur in massive numbers in the upper soil layers. Decomposition is rapid because of the large surface area/volume ratio of the small sample. At pit toilet depths of three to six feet, indigenous soil microorganisms are far less numerous, there may be less moisture, the large deposit has a small surface area/volume ratio, and the sheer volume of feces is great enough to overwhelm the local buffering capacity of the soil. In a model commonly used to explain degradation of concentrated organic matter in digestors (in sewage treatment plants) acid-forming bacteria first convert the organics to organic acids.

In a well-operated digestor, methane-forming bacteria such as Methano-bacterium then utilize the organic acids as substrate to produce methane. The methane formers are very sensitive to temperature variations, pH, acidity and oxygen and when their narrow limits of tolerance are exceeded the digestor failes to produce gas, the acids increase, the pH drops, the bacteria lose viability and the digester becomes, in the jargon, "stuck." The stuck digester can usually be started again by increasing the pH to an optimum, and reseeding with a good sludge containing viable methane-formers. The pit toilet or latrine has all the characteristics known to lead to the "stuck" digestor, and it may be possible to promote decom-position in old pit toilets by methods adapted from digestor operation.

CHAPTER 3
EXPLORATORY WORK

DECOMPOSITION RATES OF BURIED SAMPLES

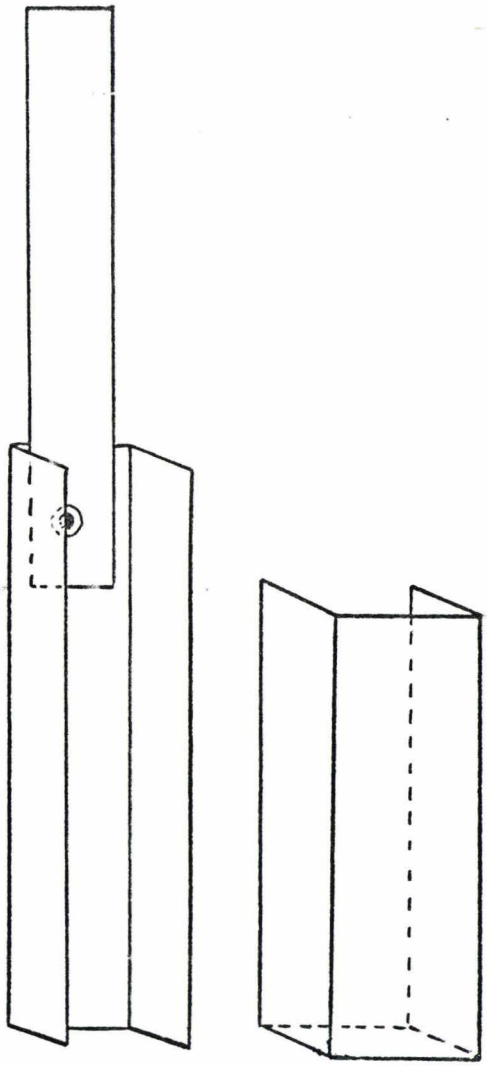
A preliminary study was made of ways in which fecal decomposition could be measured. This consisted of devising a sample holder, selecting appropriate sites, burying samples, examining samples after various periods of exposure and making a preliminary count of fecal bacteria to see how this procedure would work on such samples. The data obtained is fragmentary but is believed to furnish a good lead and to suggest some important considerations.

Sample Holders

A small sample holder was needed which would allow placement of a fecal sample and subsequent recovery, with good soil contact in the meantime. Two types are being evaluated. The first holders were constructed with sheet aluminum on three sides, aluminum window screen on two sides, and an open top (Fig. 1A). This type of holder was used in the field experiment described in this section. The other holders are made entirely of stainless steel hardware cloth and aluminum screen, with an aluminum handle fastened to the top. The new holder, shown in Fig. 1A, provides more complete contact and thereby facilitates growth of soil microbes into the feces as would occur with buried feces.

Sites

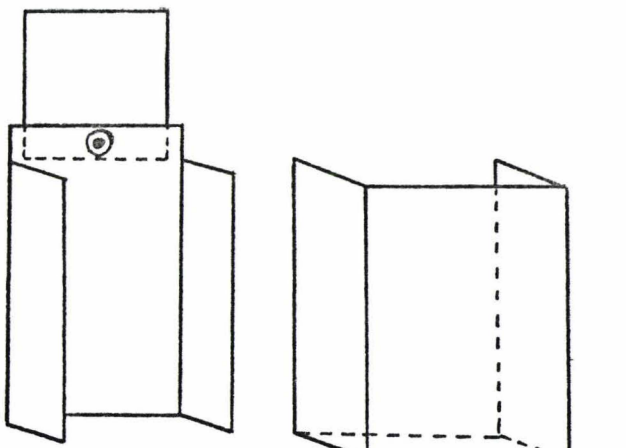
The sites used for this preliminary study were chosen close to Bozeman but in a mountain area similar to Montana Wilderness areas.



Sheet Aluminum Sample Holder with Handle

Aluminum Window Screen Cover Fits Over Sample Holder

A. Original Design



Stainless Steel Screen Holder with Handle

Aluminum Window Screen Cover

B. Present Design

NOTE: Covers are held in place by a rubber band or aluminum wire. When assembled, sample holder remains open only at the top. Screen covers the bottom.

Scale: Full size

FIG. 1. SAMPLE HOLDERS

They were located on the road to Fairy Lake in the Bridger Mountains and on the trail above Fairy Lake. They provided a considerable range of elevation and vegetation, a number of distinct soils, and some differences in climate (notably precipitation).

Sites 1,2,3 were on Cache Creek in a narrow meadow just below the cattle guard on the Fairy Lake road. The meadow has a moist soil as evidenced by appreciable amounts of sedge, along with a dense growth of waist high grasses, milfoil, lupine, thistle and numerous other forbs. Site 1 is in the center of this meadow. Site 2 is in the same location but in an anthill. Site 3 is only a few yards away but occupies a very dry site on the stream bank with a southern exposure and very sparse vegetation under scattered Lodgepole Pine. The elevation of these sites is about 6300 feet and is the lowest of the series. It would be in dense forest except for the fact that it was clear-cut a few years ago.

Sites 4 and 5 are on the saddle at the highest elevation, approximately 8960 feet. This is a long saddle running north and slightly west between Sacajawea and Hardscrabble Peaks, and is exposed to the prevailing westerly winds. Site 4, on the western side of the saddle is located in a wide strip of densely vegetated soil, almost completely covered with grasses, vetch, clover, potentilla and other plants and showing evidence of extensive pocket gopher activity in early summer. This strip alternates with strips of thinly vegetated soil on the same slope and at nearly the same pitch. Flies, spiders and grasshoppers are numerous in late summer. This saddle is snow covered all winter with only a few boulders visible and the pocket gopher and vegetation signs indicate that the snow is late in melting on the site. Site 5 is at the same approximate elevation on the eastern side of the saddle in a wide strip of reddish soil containing numerous fragments of red sandstone. Adjacent strata are calcareous. Site 5 is nearly bare with a very sparse vegetation, mostly phlox. Its winter snow cover is thin although it is immediately above talus which holds a heavy snow cover until late July.

Site 6 is a timberline habitat below the talus at approximately 8300 feet, on an open slope with clumps of alpine fir and whitebark pine. The site is on a relatively protected bench with a southern exposure, receives heavy snow but melts clear sooner than adjacent areas. The sample was not buried but placed in the lower portion of a mat of Arctostaphylos.

Site 7 is a spruce-solomon's seal habitat at approximately 7800 feet elevation. It is on a bench with a dense cover of conifers and a heavy mat of needles on the ground.

Gross Changes in Samples with Time

One fecal sample was placed at each site, buried so that the sample holder was barely visible, except as noted for Site 6. Samples are referred to by the same numbers as the sites. After twenty days (July 17 to August 6, 1974) each sample was removed briefly, examined visually and for odor and replaced. Results were as follows:

Sample 1. Unrecognizable as a fecal sample. Very strong pleasant earthy odor of the type ascribed to soil actinomycetes in freshly turned earth.

Sample 2. Heavily tunneled by ants with removal of most of the sample but visually recognizable feces attached to holder walls and a fecal odor.

Sample 3. Little apparent change and strong fecal odor.

Sample 4. Massively penetrated by a white mold mycelium with some development of an earthy odor. Not recognizable as fecal.

Sample 5. Thoroughly dried and no odor detectable. One insect larva, about 1/2 inch long was in the holder.

Sample 6. Practically all feces gone by visual appearance but fecal odor was strong.

Sample 7. A strong earthy odor with no fecal odor, but when opened the material still looked like feces.

Some tentative conclusions and comments are possible from these observations. The period of burial was a time of unusually hot and dry weather with no appreciable precipitation and with temperatures in the 80's and 90's. The water content of the feces was enough to prevent drying in several locations but not in the driest. Fecal moisture should therefore have been adequate for fecal decomposition and the temperature should have been favorable for it. Nevertheless, the feces did not become esthetically unobjectionable in most sites in this time. Therefore they were not completely humified. In the two driest sites, 3 and 5, colonization of the feces from the soil was not appreciable, so there is probably a minimum soil moisture level which is necessary for this to occur and colonization is a necessary step in humification. The most nearly humified sample, at Site 1, had such a strong actinomycete odor that it is certain the actinomycetes were still in an active growth stage because the odor diminishes as they pass this phase. This was in a soil that was damp at the time of sample placement and was still damp at the time of observation and probably the conditions were optimum for humification. Consequently a conditional conclusion can be made on the basis of this simple observation that twenty days is not long enough for humification of feces under the best conditions of this Rocky Mountain area. The fact that ants tunneled the sample but did not clean up the sample holder shows that they cannot be counted on to remove all fecal material. The most important conclusion from these observations is that a considerably longer period of trial must be used in field experiments.

Bacterial Observations on Fecal Samples

On August 27, after 41 days burial, all samples were retrieved except Sample 5 which could not be located. The weather since the first visual observation had been wet with rain and some snow at the higher elevations. No sample was snow covered, but all soils were moist. Sites 1, 2 and 3 had been heavily trampled by cattle and Sample 2 was

knocked out of the anthill. All sample holders were placed in plastic lined paper bags and stored overnight in a cold room.

Counts were made by pouring 100 ml of sterile buffer into each bag, shaking it to disperse bacteria, pipetting 10 ml into a 90 ml water blank for the first dilution and then making successive 10 plus 90 dilutions for a total of 4 dilutions in the series. The choice of dilutions was a guess made on experience with water counts. Ten ml aliquots of the dilutions were filtered through a millipore filter and incubated on standard media. The counts are expressed in Table 1 directly as the number of colonies per filter at the dilution used. Inasmuch as no rationale has been developed for relating this to the original amount of fecal material the counts are merely relative, except that it was expected that some counts would be completely negative, with no fecal organisms present.

TABLE 1

TOTAL COUNTS PER 10 ml ALIQUOT

Sample number	total coliforms	fecal coliforms	fecal streptococci
1	(4)* 444	no data	(3) 555
2	(4) TNTC	(4) 2	(4) 365
3	(4) 535	(4) 2200	(4) 1230
4	(4) TNTC	(4) 121	(4) 1144
5	sample not retrieved		
6	(3) TNTC	no data	(4) 354
7	(4) TNTC	(4) 42	(3) TNTC

*The number in parenthesis is the dilution counted.

TNTC means "too numerous to count."

Conclusions

The dilutions used were in most cases too low. Further work is needed to find appropriate dilutions; this means that the persistence of fecal bacteria is much greater than expected. In most cases, fecal streptococci seem to have survived better than fecal coliforms. Total coliform counts are extremely high and this needs additional data for interpretation. The samples from the driest sites, 3 and 5 (only 3 tested) may retain fecal coliforms extremely well. Samples which have humified to the extent that they are no longer recognizable as feces and are aesthetically unobjectionable and which would not be intentionally avoided by campers still retain high level of fecal bacteria. This supports the conclusion that further work is needed on the humification of feces with regard to health hazards. Feces buried for 41 days in summer weather at various forest and meadow locations does not become free of fecal bacteria in that time. Decomposition of feces was more advanced in sites favoring active soil microbial metabolism and migration of soil organisms into the feces. This confirms the efficacy of shallow burial in soil, and this combined with the persistence of fecal bacteria supports the conclusion that a study of fecal decomposition rates in different habitat sites would produce useful data for management of waste disposal. This type of study should be expanded to obtain good quantitative data.

SAMPLE PRESERVATION

The recovery and counting of field samples for bacterial population presents some difficulties in sample handling and storage. Water counts conducted by the MSU Microbiology Department in the mountain watersheds near Bozeman and in Teton National Park have been standardized on the basis of rapid return to the laboratory rather than field counts. In most instances these samples are obtained early in the morning and processed the same day. It is reasonable to suppose that fecal samples

buried for an extended period would be much less subject to alteration in counts during transportation to the laboratory and that the only precautions need be protection from excessive heat. This could be verified by counts in the field. Nevertheless, a preliminary experiment was made on survival of bacteria in feces at four temperatures, 16.5C (cool), 3.5C (cold), frozen overnight in the freezer compartment of a refrigerator and frozen in dry ice. Results are given in Table 2.

TABLE 2

EFFECT OF STORAGE ON BACTERIAL SURVIVAL

Treatment	Total Coliforms	Fecal Coliforms	Fecal Streptococci
cool (16.5C)	TNTC	5×10^9	TNTC
cold (3.5C)	no data	5×10^7	5×10^6
frozen	no data	3×10^6	3×10^6
dry ice	no data	no data	3×10^6
fresh sample	no data	no data	2.6×10^6

Freezing apparently lowered the number of total and fecal coliforms but not fecal streptococci. The cool treatment was apparently a low temperature incubation which increased the counts.

These results are not encouraging for the removal of field samples containing fresh feces unless fecal streptococci are used as the indicator organisms. In the Teton National Park study, a field worker camps out overnight at a site and rushes a sample back the next day. Water samples have only a few bacteria and little organic matter so the respiration rate is low and changes during transportation are minimal. Soil and fecal samples have a high count of microbes and a high respiration rate so that microbial population changes are rapid although total counts may not vary much. Consequently, some effort should be made to develop satisfactory field counts, a procedure for which the Millipore

field incubator is the only commercial one affording accurate temperature control suitable for fecal coliforms. This instrument is heavy (about 18 lbs) and it requires an automobile battery for field use. The battery would either require recharging in the field (which violates USFS regulations for Wilderness Areas) or several batteries would have to be carried (which is impractical). The investigators have developed a portable water-bath incubator that is light, inexpensive, and operates on propane, gasoline or even firewood. While it seems quite certain to work well, the prototype has not been tested and the fuel requirement is unknown as yet.

INDICATORS OF DECOMPOSITION

In addition to bacterial counts there are other potential indicators of fecal decomposition and humification (a process in which the organic matter of feces is converted to that typical of ordinary soil, a large part of which is converted to carbon dioxide and water in the process). The expectation is that the humification process would be accompanied by the destruction of fecal bacteria and their replacement by an ordinary soil microbial population which consists of several thousand species of bacteria and molds. Preliminary work was planned to include organic acids, fecal fat and respiration as other indicators of humification.

Fecal Fat

The chemical composition of human feces, like that of bears, coyotes and other omnivorous wild animals, varies considerably with diet. Fat is the least variable constituent in human feces. Among the lipids of feces, standard quick tests are available for the cholesterol type fatty components. Cholesterol type structures are measured by the formation of colored compounds on the addition of certain chemical reagents and this is susceptible to quantitative measurement. We did not conduct any laboratory work on this but the methods are standard

procedures, cheap and rapid. Fatty acids can best be determined by gas chromatography which is sensitive and reliable but requires a larger investment in time and particularly in preparation and standardization of the gas chromatography columns and readings. Once the procedure is standardized the method is suitable for the handling of many samples. Neither cholesterol lipids nor fatty acids would be expected to change much during the time of transportation of a sample to the laboratory. Microorganisms prefer carbohydrates and peptides and only digest fats when these more available compounds are depleted. Some work was done on standardization of a gas chromatograph for fatty acid determination but no experimental data is yet available.

Respirometry

Respirometric methods could be made in a variety of ways. In water microbiology, the BOD is a standard parameter but only because pure water is low in organic matter and because of that pollution is directly related to the oxidizable organic matter content of water. In a fecal sample undergoing humification the content of organic matter per gram of material would not change during humification. The kinds of organic compounds would change but the total amount would remain constant. There would still be some change in BOD if a fecal sample were dispersed in a known volume of water because humified organic matter decomposes more slowly than unhumified matter. But the measurement would not be sensitive. Total organic matter in the fecal sample would not necessarily decrease as mycelia obtaining nutrients from outside the sample would grow into it as observed with Sample 4. If a sensitive measurement of the kind of organic matter is desired as an indication of the progress of humification, the Gilson Oxygraph (or other similar apparatus) or a Warburg type respirometer would be much more sensitive than BOD. They would also give measurements in a few hours at the most. Some special vessels for the Gilson differential respirometer have been made in our laboratory and are being used in fecal decomposition experiments which have not been completed.

Conclusions

Experiments should be done to determine if any of these alternative procedures is useful in correlating fecal changes with the disappearance of fecal bacteria. In view of the 41 day burial results described earlier, it seems likely that extensive chemical changes will take place before the fecal bacteria disappear. However, even if chemical measurements are not useful in determining bacterial changes, they may be good indicators of the beginning and the state of progression of humification.

FIELD TRIPS

A number of field trips were made to obtain a first hand view of actual conditions where fecal decomposition studies might be made and to make a preliminary evaluation of the extent of any other sanitary problems that might arise with present or increased Wilderness use. Several of these trips were made in the company and with the assistance of U.S. Forest Service personnel who also provided their insight into the general problem together with much useful background on present management and on the human use of Wilderness. The Forest Service also provided many relevant publications indispensable to an understanding of the management problems facing them.

Sites Near Bozeman

A site for quick sampling was needed and after investigation of alternative areas, the Fairy Lake location was used for preliminary experiments on the buried fecal samples described. This provides a location similar to some of the Wilderness areas in Montana but suitable for recovery of samples in half a day. The Fairy Lake road is closed by snow from early fall until sometime in July so it was thought that the

Bridger Bowl ski area, allowing year around access, would be better for a permanent site. This would provide a relief of about 2500 feet and some valley, forest, and alpine conditions.

Selway-Bitterroot Wilderness

The Big Creek drainage was visited on July 21-23 by the authors in cooperation with the following Forest Service personnel: R. Lucas, C. Hardy, W. Holman, R. Gardner, M. Paterni, and D. Barker. We made the circuit up the Big Creek trail, the South Fork, across the divide into the Big Creek basin. This area presents several habitats which are uncommon or absent on the east side of the continental divide near Bozeman. Vegetation is generally more abundant and diversified. The canyons are deep and narrow and heavily timbered. Alpine vegetation is notably more luxuriant. Some of the stands encountered which are absent in the Bozeman area were western red cedar, larch and ponderosa pine. The several forest habitats are described in Forest Habitat Types of Montana by Pfister et al (1974). One of the interests in the Big Creek area was the recent closing of some campgrounds on Big Creek Lake. Some violation of this closure was noted during our trip. The closure exerts population pressure on the remaining campgrounds at the far end of the lake. An impression of several of the party was that closure in this type of area is needed on the basis of protection of the physical and vegetation features of the campsites before a sanitary hazard would arise. However, the limitation of camping sites would tend to increase a sanitary problem by concentrating campers at the few campsites which remained open.

One of the objectives was to locate a site which would be near water, but unused by campers to serve as a control for counts of fecal organisms. No such site was located, as campfire remains were present at all lakes, even those near the divide above timberline. There were many small tributaries of Big Creek that might serve in such a capacity, but most of these are used in hunting season, according to reports.

An aerial survey of the area was subsequently made by Temple and McFeters of MSU, accompanied by R. Daniels from the Forest Service. The principal purpose was to identify an area which would furnish two similar sites, one used by people and one unused, similar to the situation which McFeters employs in his studies of the Teton National Park water pollution study. No suitable area could be found in Big Creek as the only unused lakes appeared to be exceedingly difficult of access and consequently time-consuming to use for experimental work. However, the next large canyon to the south, on the return portion of a trail going past Big Creek Lake over Packbox Pass into Idaho and back into Montana appeared to be ideal for such a comparative study. This would be readily accessible and give a contrast between a regularly used campsite and an unused similar area. The only disadvantage is that samples could not easily be removed in a single day if one person were sampling both sites so field incubation would be essential. Our conclusion is that this part of the Selway-Bitterroot Wilderness would furnish several different habitats which would not be observed nearer Bozeman and would furnish an actual example of present Wilderness use, with a suitable opportunity for control measurements on areas not frequented by people.

Salmon River

A portion of the Salmon River Wilderness was visited on a Forest Service patrol boat in the company of W. Holman and R. Lucas of the Forest Service. The objective was to inspect the camping sites which are limited by the steepness of the canyon to large sandbars and occasional level sites at the mouth of tributaries, with an occasional small bench offering possible other small campsites. The scenic nature of the river is such that certain sandbars are preferred as campsites and human use is concentrated on a small portion of the river bank. In addition to float trips, the area serves to provide hunting camps. At the time of our visit, the water was too cold for floating and the hunting season was about to start, so at a few locations there were a large number of

pack animals coralled near the river. Most of the steep canyon walls had the mixture of open rock and scattered timber that is typical of sheep habitat. Aside from hunter use, most human traffic is by river. The area was formerly homesteaded at each tributary whose mouth was wide and flat enough to garden; these locations are now used as hunting camps. Drinking water is presumably obtained by most users from the smaller tributaries, although some people probably use river water for cooking and drinking as it is clear and cool. Consequently, it might be advantageous to analyze both river and stream for quality and water stage to assess the washing of human and animal wastes into the river. The studies on watersheds done at Montana State University demonstrate that total coliform counts would not be useful in such an area since the game population is very little restricted in movement by human presence and consequently the tributaries would contain large numbers of coliforms from wild animals. There was no visible evidence of fecal pollution of the campsites except for one fecal sample under a rock at a hunting camp. Interestingly, this fecal material was in plain sight of a well kept pit toilet and indicated a dislike of the use of the pit toilet. Horse and mule feces were abundant at the hunting camp and were probably washing into the river via a tributary which at that point overflowed the land in multiple channels through an area used for grazing. It was the site of an old apple orchard which had attracted the stock.

No samples were taken on this trip. The area would be suitable for experimental use with sample retrieval by means of the patrol boat and some conclusions could be made on the sanitary quality of sandbank campsites without an extensive study. The Salmon River is about a four hour drive from Bozeman. Retrieving samples and returning them to the laboratory would be easier here than in the Selway-Bitterroot Wilderness. It would be simple to obtain information on human waste disposal practices in this area. In some respects the Salmon River has factors in common with the Boundary Waters Canoe Area, namely that travel is by

water and campsites are consequently restricted. However, present management is quite different. The similarities are imposed by the physical nature of the Wilderness and not by regulation. One major difference is the provision of pit toilets in the BWCA.

Boundary Waters Canoe Area

Some of the BWCA area near Ely, Minnesota was inspected in October with J. Lekatz of the U.S. Forest Service. As in the Selway-Bitterroot area, one aim was to locate possible control sites which would be similar to designated campsites except for the absence of human use. As in the Bitterroot area, closures of campsites were observed. They were closed on the basis of destruction of soil and vegetation rather than because of sanitary considerations. The area is unique in having specified campsites with fixed fireplaces and well-kept pit toilets. An eminently suitable control area was found, a short walk from an established canoe route. The site is on a lake that is ideal in all respects: (1) it is being comparable in size to many on which campsites exist, (2) it has the same wildlife and vegetation, and (3) there were no signs of human visitation.

There are a number of distinct forest habitats in the BWCA but the establishment of pit toilets makes the need for fecal humification studies questionable. A different type of sanitary problem seemed possible from campsite inspection. Pit toilets were established uphill from the campsites which are usually on the lake front. Water for drinking and cooking is obtainable only from the lakes in most instances because there are few streams. One of the pit toilets was located in a shallow gully, and judging from the surface contour, drained into the lake near the campsite. There was water in the toilet which indicated seepage through the ground. If the pit toilets are always used, water contamination is probably the only possible sanitary problem in this area. Sample retrieval from BWCA sites would be very slow and hence field incubation would be required. The BWCA is much more intensively

used than any of the other Wilderness areas we inspected. The BWCA has been the subject of many management studies and is well described. Registration of users gives a good use figure for relating field observations. In addition to the well-used canoe routes, it should be noted there is increasing use of the hiking trails. This would pose an entirely different problem of waste disposal. In contrast to mountain areas, hiking is relatively restricted to trails by the number of lakes, the denseness of the forest growth, and the lack of vantage points for scenic viewing.

REVIEW OF RELATED STUDIES

Although little is known about how the decomposition of feces affects the inactivation of pathogens at single-use sites, there is a considerable amount of literature concerning ancillary problems. A review of these related problems promotes general understanding of this one.

Management

Lucas (1973) detailed visitor impacts as: loss of vegetation and soil, water pollution, littering, vandalism, and wild life conflicts. He asked, "what is the human waste absorptive capacity of different soils at different elevations?" He discussed several management options and the desirability of information-persuasion-education versus mandates and concluded that some form of management for Wilderness Areas is required and furthermore the management must be one of use. The concept of a management of use was further clarified by Hendee and Stankey (1973) who compared anthropocentric management which envisions man's use as the primary objective and biocentricity in which the emphasis is upon the natural environment at the expense of recreation. They stated the then-current U.S. Forest Service policy was tending toward biocentricity but extensive debate is needed to resolve the issue. Their analysis of emerging U.S. Forest Service policy was confirmed by the USDA Forest

Service (1973) in a position statement by Region 1 as follows: (1) trails are to resemble game trails as much as possible, (2) existing administrative structures are to be phased out and even fire lookouts are to be removed if other means of fire spotting is found to be workable, (3) no new permanent toilets will be installed until justified and approved in the management plan, (4) present toilets are to be removed if not justified in the management plan, and (5) users must rely upon their own judgment for determining the potability of water.

In Teton National Park, signs were constructed warning that some water supplies might be unsafe. These were removed when the coliform counts were attributed to wild animals. The question of responsibility is a difficult one. Whether a laissez faire attitude toward water potability can become permanent policy remains to be seen. The public has fallacious notions about sanitation and some protection (perhaps in the form of education based on sound research) may be required.

The use of travel permits is mandatory in some wilderness areas and the requirements of permits is increasing according to Lime and Lorence (1974) who felt mandatory permits were beneficial. Mandatory permits provide recreation managers with better use estimates but such use estimates usually require correction because not all visitors obtain permits. Lucas (1974) re-emphasized the value of travel permits because they make research and communication more effective. In discussing the findings of research to date, he stated large parties reduce wilderness feeling according to 75% of those polled in the Boundary Waters Canoe Area and 90% of those polled in the Bridger Area. According to 70% of the users, litter was of more concern than numbers of people and at least 1/3 of the users felt the Wilderness was being overused. Lime (no date) emphasized the difficulty of obtaining use data and camper attitudes and he concluded much research was needed. However, the limited research accomplished to date showed water-front campsites, fishing, seclusion, and diversity were obvious requirements.

Management must ultimately come to grips with carrying capacity because of the continuing increase in the use of wilderness areas. Stankey, Lucas, and Lime (1974) have stated National Forest Wilderness use has increased steadily at a 10 to 12 percent annual rate since estimates were begun nearly 30 years ago. From 1950 to 1970 reported visits increased from 250,000 to more than 2 million. Data on use intensities were given for 9 Wilderness Areas where the intensity of use ranged from a maximum of 4.8 visitor days per acre in the Desolation Wilderness through 0.9 visitor days per acre in the Boundary Waters Canoe Area to 0.1 in the Selway-Bitterroot Area and the Bob Marshall Areas. Visitor days per acre is misleading, however, because the use may be concentrated at isolated points or along narrow belts. For example, the Boundary Waters Canoe Area receives intense use along the shoreline, particularly at established campsites, and very little use elsewhere. Consequently, the authors have developed a concentration index based on ratios of areas bounded by curves plotted on gross accumulative percent visitor miles versus cumulative percent trail miles. Analyses based on such concepts increase our understanding of congestion, and were this information made available to the public, it would permit those who seek solitude to find it.

A sizeable body of published literature concerning carrying capacity research has been published and Stankey and Lime (1972) list more than 200 papers related to carrying capacity decision-making. These papers deal with physical, biological, and social interaction dimensions of the problem. There is a growing understanding of the concept of carrying capacity, and most definitions call for use limitations at some point that will neither adversely affect the resource itself nor the recreational experience of the user. Nevertheless, the concept has not been completely grasped because of the lack of a systematic conceptual framework to define the major issues and the research needed to resolve such issues. It is usually assumed that increasing use results in quality decline whether in recreational experience or ecological condi-

tions. Such oversimplification has often led to the conclusion that restriction on visitors was the only effective solution, but Frissell and Stankey (1972) have both conceptual and empirical reasons to doubt such a conclusion. On the assumption that ecosystems are dynamic and changing, these authors propose a model of acceptable ecological variation in which the perturbations caused by nature lie at the middle of a spectrum bounded on both sides by man-caused change. At some point within the man-caused change, there is a limit of acceptable change (LAC). A considerable quantity of research and the blending of many opinions is required to determine just what is the LAC. The authors propose that a rational answer is dependent upon both the place and the kind of impact. In one situation the impact might be coliform count, in another, it might be number of users. There are no clear unequivocal answers because wilderness users are not a homogeneous social unit. But management objectives cannot be fully satisfied without adequate research input on all fronts of impact including the complex, interrelated nature of these impacts.

As a result of sampling visitor perception of carrying capacity, Stankey (1973) found wilderness users in the Bob Marshall, Bridger, High Uintas, and Boundary Waters Canoe Area: (1) to be critical of crowding, (2) to conflict with other types of users (for example, backpackers resent horseback riders), and (3) to be particularly critical with respect to level of use and their inability to find isolated campsites. It was suggested that party sizes be limited, that motors be restricted in the Boundary Waters Canoe Area and that off-season use be encouraged. There has even been some mention of zoning.

Many writers have complained of overuse of wilderness areas in general. Typical is Cowgill's (1971) complaint of the overuse of limited campsites on the Colorado River particularly with respect to human waste sanitation. Users complained of litter, rundown sites, lack of isolation, large parties, scarcity of campsites, and invasions by aircraft. Secretary of Interior Stewart Udall, upon seeing mountains

(sic) of litter and toilet paper blooms at ad hoc toilets, ordered it cleaned up. Human waste sanitation was implied to be the most important problem in this area, and managers will eventually have to resolve the collision course between protection of the natural state of wilderness areas and the enjoyment of such areas by man. As another example of the dilemma faced by wilderness managers, Wood (1971) stated that the Desolation Wilderness was one of the most heavily overpopulated Wildernesses due to its easy access to the large population centers of central California and to its natural beauty. Permits were required for Desolation Wilderness users beginning in the summer of 1971. And the U.S. Forest Service was studying measures to protect the Wilderness including reducing trail maintenance, removing existing toilets and other improvements, creating buffer zones, and prohibiting the burning of natural fuels.

In contrast to western managers' decisions to remove toilets, toilets are recognized as a necessity in the Boundary Waters Canoe Area where the major concern with pollution is how to make them function better according to Merriam et al (1973). These authors studied 33 Wilderness campsites in the Boundary Waters Canoe Area for a period of 5 years to determine the impact of visitor use on soils, vegetation, vandalism, site enlargement, and more specific factors such as exposure of tree roots, dying trees, accelerated erosion, and the effect of sanitary wastes. The BWCA Management Handbook (1969) specified criteria for the permanent closure of campsites where occupancy will cause permanent loss of vegetative cover, excessive loss of soil, or serious water pollution. The Forest Service has closed sites where the above conditions prevail, particularly when there was no adequate location for a latrine. The standard latrine consists of a substantial wood structure about two feet high, two feet wide, and two feet long with a hinged cover. There is no surrounding structure, but the latrines are effectively screened by long winding trails in thick vegetation. Visitors may camp only at designated campsites which invariably have a latrine,

and it is obvious that without the latrine there would be noisome toilet paper "blooms" at such heavily used sites.

Proudman (1975) has described the use of helicopters by the Appalachian Mountain Club to remove wastes from the backcountry of the White Mountains of New Hampshire and in Maine where soils are inadequate for leaching fields. A 55 gal steel drum with a 4 mil liner is located under the toilet seat in a watertight vault. When full, it is removed with a hoist and hauled to the landing pad. Its advantages include: (1) almost guaranteed protection of water supplies where soils limit the options for disposal, (2) maintenance by the inexperienced, (3) low installation cost, and (4) usefulness in freezing weather. However, its disadvantages include: (1) cost of helicopter service to raise the total cost of handling to about 30 cents per person-day, (2) strict regulatory restrictions and regulations, (3) unfavorable reaction from some hikers and campers who regard it as technological over-kill and who deplore the unsightliness of landing pads and barrels of waste and the "sight and sound" of aircraft in a "wilderness" setting, and (4) various technical problems such as the need to bail the vaults because of condensation or rainfall. The Appalachian Mountain Club is experimenting with other systems, particularly with the Clivus system. Cook (1974) is also experimenting with the Clivus system as well as with oil-flush toilets.

Sewage Treatment for Low Discharges

The low volume of wastes generated in camping places creates a dreadful problem for disposal. There is too much waste for careless disposal and too little for the effective use of the usual physical and biological treatment plants. However, physicochemical treatment holds promise and Fullerton (1974) describes an oil carriage system in which the wastes, after separation from the oil by gravity, are burned. Because the amount of wastes are less than 2 percent of those using

conventional flush toilets, the amount of fuel needed for incineration is not great. Where wastes can be stored for a period of time until a sufficient quantity has accumulated, they can either be trucked to conventional treatment plants or treated on site by mobile physicochemical treatment plants as described by Simmons and Phen (1973). A mobile unit, mounted on a truck or a trailer can either travel from vault to vault and treat the wastes on site, or it can be parked in some central location with the vault wastes trucked to the processor.

During the summers of 1967 and 1968 waste incineration was tried under actual use conditions at 10 or 12 locations in the BWCA of Superior National Forest by Barton (1975). Water quality surveys had shown: (1) nutrient levels were nearly great enough to trigger aquatic nuisance and (2) many campsites were on very shallow soils over bedrock where the pit toilet would not adequately prevent seepage into the lakes. The purpose of the trial incineration was to guard the waters from nutrient additions and to prevent contamination. For practicality, the constraints placed on the design were: (1) low cost, (2) low maintenance, (3) easily serviced, (4) no mechanical noise, (5) operable in winter. The latrine consisted of an 80-pound cast iron pot 28 inches in diameter by 20 inches deep under a standard wood bench. Latrines were serviced during routine clean-ups (weekly to monthly depending on use). Clean-up crews carried a 100,000 BTU torch which was inserted at a 30° angle into a lid temporarily placed on the pot. The lid was also fitted with a short stove pipe for draft. It required 10 to 12 pounds of butane and 60 minutes to incinerate the waste whereas a burn time of 30 minutes was needed. Several means to decrease burn time were tried and while some were moderately successful, personnel safety became a concern. The budget did not permit a complete evaluation of the improvements envisaged.

The use of soil systems of one kind or another possesses a great many advantages as explained in detail by CH2M (1972). Soil systems

include "closed systems" (such as evapo-transpiration units), spray irrigation, soil incorporation (in which raw sewage may be buried to a depth of 6 inches in a trench which is immediately filled in behind the burial unit), leach fields or drain fields for septic tanks, pit toilets, simple burial, and even surface deposition. The tremendous adsorptive, buffering, and ion exchange capability of soils as well as the concentrated and active biological community of organisms near the surface has been well documented. Healy and Laak (1973) have found more than 99 percent BOD removal from septic tank wastes in drain field systems.

Bernhart (1973) described in detail evapo-transpiration systems in which untreated wastes are discharged into a large shallow basin lined with rubber or plastic to prevent seepage and filled to a depth of several feet with rock at the bottom graded to sand near the top which is covered with a layer of straw and, finally, 12 to 18 inches of soil. Water is removed by a combination of evaporation and the evapo-transpiration of plants. The heat produced from the biochemical reactions in the sewage keeps the surface warm, and even in cold climates a rather long growing season can be obtained. Hasfurther (1974) is studying an evapo-transpiration waste disposal unit for semi-primitive mountain environments for the USDA Forest Service Rocky Mountain Forest and Range Experiment Station. The suitability of other types of closed-system waste disposal means for semi-primitive mountain environments is under study for the USDA Forest Service Rocky Mountain Forest and Range Experiment Station by the Agricultural Engineering Division of the University of Wyoming (1973). This study includes the upgrading of lagoon performance, and the identification, evaluation, and guidelines for site conditions for sprinkler irrigation. Dickerman (1974) has listed all of the U.S. Forest Service sewage disposal research efforts extant as of June 1974. It includes projects at Pennsylvania State University, College of Forestry at State University of New York, University of New Hampshire, Stockton State College, and Montana State University.

Spray irrigation has been the subject of extensive research and literature. Proceedings of several conferences have been published including proceedings edited by Kardos and Sopper (1973) and Sanks and Asano (1974). Aside from obvious problems such as inadequate infiltration capacity and subsequent ponding or runoff and problems of maintenance and operation, the most serious problem is the possible health hazard due to pathogenic bacteria and viruses. This health hazard is not confined to spray irrigation. The problem is much the same whether the disposal method is soil incorporation, leaching fields, or pit toilets. The magnitude and other details of the problem vary from method to method, but work which has been done on any one of the problems can be applied qualitatively -- although not quantitatively -- to other problems. One such problem is the survival and movement of bacteria through the soil and Glantz and Jacks (1967) investigated the significance of the survival of Escherichia coli in the ground after spraying with domestic waste effluent. They found the density of coliforms decreased from 582 per 100 ml at the surface to 1 coliform per 100 ml at a depth of two feet where sampling dates extended over several months.

A problem unique to spray irrigation is the generation of aerosols by the spray machines and these tiny droplets can be blown considerable distances by winds. Sorber, Schaub, and Bausum (1974) have considered the risk of inhaling pathogenic aerosols near spray irrigation sites. As much as 1/10 to 1 percent of the total water sprayed may turn into aerosols, and since viruses are not greatly reduced by primary and secondary treatment, the aerosols may contain between 600 and 6000 PFU (plaque forming units) per liter. Sunlight, low humidity, time, and temperatures above 80°F reduce viability. An 800 meter buffer zone usually provides 100-fold reduction of PFU, but the use of a buffer zone is undesirable as the only criterion for reducing virus in aerosols. To reduce public health hazards sufficiently, virus should be destroyed before spraying.

Considerable work has been done on the design of leach fields and the reason for their indifferent success, but in spite of research findings most leach fields continue to be constructed according to simplistic practices which are known to hasten failure. McGauhey and Winneberger (1963) discovered the bottoms of carefully leveled trenches tend to remain saturated causing excessive biological growth which clogs the pores. Side walls which are alternately wet and dry constitute a less favorable environment for clogging bacteria and hence side walls are more effective for the infiltration of water than is the bottom of the trench. They urged drain trenches be constructed as narrow as possible and with sloping side walls. McGauhey and Krone (1967) have further defined the role of bacteria in the use of soil mantles for wastewater treatment systems.

Winneberger and Klock (1973) found a very large variability in the standard percolation test even when test pits were only a few feet apart. When the test pits were constructed and operated by different consulting soils specialists, the results were even more variable. Healy and Laak (1972) presented a mathematical analysis of percolation tests which shows the standard percolation test is quite unreliable. In a later work (1973) the same authors presented two methods for accurately measuring the hydraulic conductivity of soils and presented design examples using their methods. Popkin and Bendixen (1967) found that dosing once per week and better pretreatment of the wastewater sent to the leach field resulted in improved hydraulic conductivity but these findings were refuted by Kropf, Healy, and Laak (1974) who concluded intermittent dosing, periods of rest, and other methods of improving hydraulic conductivity were ineffective. They concluded the most effective means for infiltration is to increase the infiltration area or to increase the hydraulic gradient.

The incorporation of raw vault waste applied in furrows 6 inches deep and 2.3 feet center to center at an injection rate of 0.5 gallons

per foot was reported by Cunningham and Urie (1972, 1973). In the first year of this study, Cunningham, Tluczek, and Urie found the typical vault waste analysis to be: total solids - 2.8 percent; Kjeldahl nitrogen - 3860 mg/l; ammonia nitrogen - 34 mg/l; phosphorus - 574 mg/l; fecal coliforms - 1.74 x 10^6/100 ml; Enterococci - 3.23 x 10^7/100 ml. The incorporation of vault wastes applied 270 pounds per acre of nitrogen and 40 pounds per acre of phosphorus. Ground water under the incorporation plot showed a high increase in nitrogen but no bacterial contamination at a depth of 8 feet except after large amounts of water followed the application of the vault waste. Their tests showed 12 inches of soil was adequate to remove coliform bacteria but high titers of coliforms persisted for several months and according to Urie (1974) some coliform organisms survived for more than 14 months. Leonard (1974) applied raw sewage to the surface of three 8 foot diameter lysimeters filled to a depth of 15 inches with forest soils. No fecal E. coli appeared in the leachate after a period of two weeks. Leonard has also qualitatively related the performance of privies to sil type but not in a formalized manner.

Pit toilets or latrines are used extensively in the Boundary Waters Canoe Area and to some extent in other Wilderness Areas but Barton (1969) stated the common pit toilet may be inadequate in some physiographies for the protection of public health and for preserving environmental quality. Boelter, Urie, and Morgan (1974) stated that peat has a higher cation exchange capacity (2 to 3 milliequivalants per gram) than clay (which they stated usually has 2 to 3 tenths milliequivalents per gram. Boelter (1974) is cooperating with Prettyman on the use of peat in toilets, and they propose to construct 8 or 10 toilets to exemplify a range of conditions in the Superior National Forest. The toilet pit is lined with a waterproof membrane inside which is a lining of peat approximately 12 inches thick. The waterproof lining leads to a container which traps any effluent from the peat. Prettyman (1974) has

monitored two peat-lined toilets for nitrate nitrogen, pH, and phosphorus. Only about three pints of liquid has filtered through the peat in three years even though the peat-lined vaults are small and fill in about four months. The nitrate nitrogen content of escaping fluid was less than 10 mg/l and the phosphorus was less than 1 mg/l which is 5 to 10 times less than the phosphorus in the native soils.

Stanlick (no date) has investigated the treatment of septic tank effluent with underground peat filters. The filters were lysimeters 46 by 188 cm in surface area. From top to bottom the lysimeters consisted of 15 cm of earth, 30 cm of gravel, 30 cm of peet, 60 cm of sand, and 8 cm of gravel. Applying approximately 5 cm per day of septic tank effluent, the following removals were obtained: coliform bacteria approximately 100%, nitrogen 85%, phosphate 20%, total suspended solids 90%. BOD-5 (5-day biochemical oxygen demand) was not given for the above conditions but where filtered septic tank effluent was applied to a lysimeter the reduction of BOD-5 was 87 percent.

Public Health Hazards

The long history of the use of the coliform bacteria concentration as an indicator of health hazard has given the test an aura of authenticity that occasionally leads to misinterpretations. The arguments for the use of the coliform bacteria test are weighty. First, the test is simple, relatively cheap, and relatively quick. Second, all human waste contains coliform organisms. Third, while the presence of coliform organisms is not a sure indication of contamination, the absence of such organisms is a reasonably good indication there is no fecal contamination. Fourth, compliance with U.S. Public Health Service Standards on bacteriological quality of water with respect to coliform organisms virtually eliminates water-borne transmission of disease. Fifth, even in an epidemic, there are many orders of magnitude more coliform bacteria than pathogenic bacteria so searching for pathogens is difficult.

But on the other hand, some pathogenic bacteria and most viruses are more resistant to standard disinfection practices than are coliforms, and in heavily polluted waters, the absence of coliforms is no guarantee of the safety of the water. Nevertheless, Geldreich (1970) stated the fecal coliform test is the best indicator of pollution, particularly in clean streams because of the excessive difficulty of finding pathogens. In correlating pathogens to indicator organisms, he found a sharp increase in Salmonella above 200 coliforms per 100 ml. Microbiologists generally consider a positive coliform test to indicate possible human fecal pollution and a negative coliform test to indicate that human sewage is not present in the water.

Tluczek (1974) stated incorporation of vault wastes (plowing vault wastes into the ground) gives a minimal public health hazard. He found that the addition of 5 percent lime reduced coliform titers drastically in 1 hour. He surmised that house fly contact with incorporated vault waste was probably minimal, although it seems to be generally accepted by microbiologists that pathogenic bacteria ingested by larvae can still inhabit the host at adulthood. Studying the viral hazards of incorporation of vault wastes, Buller (1974) found soil columns flushed once with water retained all but 10^{-6} percent of initial bacteriophage T_4 and 10^{-2} to 10^{-3} percent of polio virus. He concluded there was a low grade of danger of contaminating ground water.

Bacteria tend to occur in clusters in the soil according to Krone, Orlob, and Hodgkinson (1958) who also found two mechanisms, straining and sedimentation, to account for the entrapment of bacteria by soil. The soil surface is the most important place for straining to occur. But when bacteria builds up too thickly, clusters break loose and thereafter the more important mechanism is likely to be sedimentation. The combination of these two mechanisms results in peculiar breakthrough curves in plots of bacteria passing through soil versus bacteria applied. There may be a considerable period before any bacteria pass followed by

a cascade of many bacteria passing. These phenomena are later replaced by either steady-state, declining rate, or increasing rate of bacteria passing. The number of bacteria passing decreases as the path length through the soil increases, and although generalizations are likely to engender inaccuracies, it appears that the first few millimeters of a sandy soil is as effective as the next 2000 millimeters in reducing the amount of bacterial travel by powers of 10. Furthermore, bacterial travel is a function of the characteristics of the medium and the accumulation of sewage solids and bacterial slimes which produce a defense against bacterial penetration. After bacteria first penetrate the column, the concentration of bacteria in the effluent continues to rise to a maximum after which it decreases suggesting that the accumulating bacteria improve the straining method of removal. The mechanical instability of the clusters of bacteria held by the soil then results in a cascade of organisms and a rapidly advancing front of saturated straining sites. When the capacity for removal by straining has been satisfied, sedimentation alone is operative and the concentration of bacteria in the effluent remains constant. When the soil is unsaturated, the clusters of bacteria tend to be smaller with a consequent lower removal rate of bacteria. The authors concluded the soil surface plays a dominant role in the removal of bacteria and it operates in a manner to restrict continued bacterial infiltration. Furthermore, the interpretation of experimental data depends upon estimation of the densities of the individual bacteria or the bacterial clusters. Evidently, the correct interpretation of experimental results is difficult at best and in experiments which are not very carefully controlled, the results can be quite misleading.

Coliforms in mountain watersheds. This subject has been investigated by several workers in the Rocky Mountain area, particularly at Montana State University, Colorado State University, and at the University of Idaho. By far the most extensive series of studies are those carried out by Montana State University over a number of years, first

by Bissonnette and Walter (1971) and subsequently by Stuart (1971, 1974) and McFeters (1974). The studies were begun to determine the comparative water quality of open and closed watersheds supplying the City of Bozeman. One watershed (Hyalite) has always been open to public use and one (Mystic) was closed in 1917 and not reopened until 1970. The studies have provided a better understanding of: methods applicable to the counting of fecal organisms in pristine waters, appropriate sampling and handling conditions, and comparative water quality. It has also demonstrated interesting facts about the contamination of water by wild animals. This information was revealed by a series of studies which followed the observation that the open watershed had lower coliform counts than the closed watershed. The pollution was traced to the substantial elk population in the closed watershed with additional contributions from bear, deer, and moose. Human activity in the open watershed kept animals away from the streams most of the time and consequently bacterial counts were low. When Mystic was opened to the public in 1970, the bacterial counts were reduced as people pressure drove the elk to higher elevations or to other canyons. This study is still under active investigation, particularly in regard to the survival of specific bacteria immersed in the streams in chambers which permit the flow of water but prevent the ingress or egress of bacteria.

McFeters (1974) has studied water quality in high, alpine wilderness in Teton National Park for several summers. Two parallel, adjacent canyons have been utilized for the investigation, comparable in most respects in topography, vegetation, and stream flow. One is used very heavily in the summer by hikers and some mountain climbers, the other is seldom visited and has a much greater population of wildlife as a consequence. For example, the grizzly is present in the control area but rare in the other canyon which is used for hiking. Studies at the present time are being made on the contribution of natural stream flora to the coliform count and on the survival of specific bacteria. The National Park Service has made some alterations of its water use recommendations in that part of Teton National Park as a result of the study.

Both of these studies, which are similar in character, have contributed to the interpretation of the standard tests for water quality in the relatively pure waters of mountain streams. Most other water quality studies conducted in the United States deal with water which is grossly polluted by comparison with these mountain streams.

Coliform, fecal coliform, and fecal Streptococcus tests were used by Kunkle and Meiman (1968) to investigate bacterial fluctuations in a small stream at high elevation in the Colorado Rocky Mountains in 1966 to 1967 with a total of more than 3000 observations at two sites. The upper site was located to sample water from a high uninhabited, forested catchment, and the lower site (1 1/2 miles downstream) was taken below a grazed meadow irrigated by the stream. Statistical analyses showed a coefficient of variation of about 0.5 for coliform replicates taken from the same sampling bottle. Two bottles collected simultaneously gave similar bacteriological counts. More variation occurred on a day-to-day basis than within a day. Variations were highest when the bacterial count was the lowest. Samples taken in the evening showed the highest counts whereas samples obtained in the morning showed the lowest counts, and midafternoon samples fell between the two. This cycle was apparently related to the rising stream stages in the early evening which caused a flushing action to take place along the banks of the stream. The flushing action was very pronounced during summer storms when on a rising hydrograph. This was followed by low bacterial counts on the falling hydrograph. Water temperature was inversely related to bacterial counts, and exposure of the bacteria to sunlight for one to two hours gave extreme die-off to such an extent that this factor alone might account for low afternoon bacterial counts. The downstream site containing runoff from the meadowland where cattle grazed always showed higher bacterial concentrations than the upstream site. Fecal coliforms were more sensitive in detecting pollution than were coliforms and far more sensitive than fecal streptococci. The ratio between fecal coliforms and fecal streptococci was less than 1.0 at high elevations and

between 1.7 and 5.5 at the lower elevation. Perhaps the most significant finding of this study is the danger of depending upon a few samplings from which to draw conclusions. Sampling must not only be extensive but it should be carried out at different times during the day and at different times with respect to precipitation lest conclusions be totally erroneous.

McFeters and Stuart (1972) discovered that fecal coliforms are short-lived in natural waters and are therefore not particularly good indicator organisms. Indeed, under some circumstances, fecal coliforms are the first organisms to die in an aquatic environment and the die-away can occur in a few hours. Salmonella show similar survival characteristics and both decline more rapidly than other organisms of public health significance. McFeters et al (1974), using membrane filter growth chambers which allowed water to diffuse through the membranes but prevented the bacteria from leaving the chambers, found coliform cultures died more rapidly than enterococcus cultures. The comparative survival of organisms beginning with those of longest life were: Aeromonas, Shigella, fecal streptococci, coliforms and some Salmonellae, Strepococcus equinus, Vibrio cholerae, Salmonella typhi, Strepococcus bovis, and Salmonella enteritidis. Stuart and Jezeski (1974), utilizing growth chambers in streams, showed cellular injury was caused by an aquatic environment. The use of a selective medium as specified by Standard Methods (1971) inhibits the recovery of the injured organisms and gives spuriously low counts. The M-FC medium used with the membrane filter method gave especially poor recoveries. However, the injury is reversible and can be repaired by exposing the organisms first to a non-selective medium such as trypticase soy yeast extract broth for two hours. The organisms are gradually able to recover and after this period of recovery can be transfered to the selective medium with good quantitative results.

Survival of fecal organisms in soil. This topic has been the subject of much speculation and insufficient study. Most actual studies

on bacterial disappearance are from sewage and not from soil. Both spray and trough irrigation with sewage effluent have been used experimentally for a number of years and the soil acts effectively in this case to destroy fecal bacteria, but the system is used on fields or woodland from which people are excluded. Furthermore, it involves penetration of an aqueous suspension and solution into soil which is more favorable for decomposition than the burial of feces.

One of the principal investigators has been a consultant to the disposable diaper industry in the evaluation of sanitary hazard studies sponsored by that industry. These unpublished studies indicate there is a potential hazard in sanitary landfill operations when disposable diapers are put in the garbage. Published data on the hazard of viruses in disposable diapers is hotly disputed. Peterson (1974) reports the isolation of poliovirus and echovirus from disposable diapers. Infants carry far fewer viruses than older children and adults so it may be concluded that viruses will be present in the feces deposited in campsites. The debated question is whether this constitutes a health hazard. Those who minimize the possibility point to the absence of epidemiological reports linking diapers and their disposal to infections. Unfortunately, epidemiological studies have not been made, or at least no such reports are known. In general, the immediate source of virus infections is unknown unless there has been close contact with another patient. An extrapolation of this to fecal disposal in Wilderness comes back to the hypothesis that a health hazard will exist when Wilderness use is sufficiently heavy that persons come in contact with feces carrying the specific pathogenic virus. In view of the preliminary study on bacterial decomposition of buried samples of feces, an operating hypothesis should be that viruses will persist in buried feces for many weeks or months.

Cooper, Potter, and Leong (1974) studied the survival and migration of virus in landfill leachates due to disposable diapers. Using 16 lysimeters 3 feet in diameter by 5 feet deep and two lysimeters 3 1/2

feet in diameter by 10 feet deep, they found freezing and storing virus for later laboratory examination resulted in 95% kill. Virus could survive in fills and was carried by the leachate in cascades (as had been predicted by Krone, Orlob, and Hodginkson, 1958) and not in any graded, orderly way. Virus recovery was sporadic, low in numbers, and was primarily dependent upon saturation of the soil. Saturation gradually reduced virus survival. The migration of coliphage T7 and polio virus 1 in a sandy forest soil was studied by DuBois and Sagik (1974) who applied virus to the top of columns 19.5 cm high. There was an immediate breakthrough of virus amounting to 12 percent T7 and 3 percent polio 1 with 1 liter of distilled water. These authors concluded rainfall (which except for absorbed gases is somewhat similar to distilled water) causes sorbed virus to desorb and migrate. In somewhat similar columns, Lefler and Kott (1974) found bacteriophage f_2 and polio virus 1 movement was a function of the cationic concentration of water. Removal by the sand column was excellent when the water contained .01 normal calcium ion, but it was poor if the calcium ion were at low concentration. Approximately 1 percent of the virus survived 60 days and it required approximately 175 days to achieve a near-total kill. Low temperatures (below 8°C) enhanced survival and consequently 20 percent survived for 175 days. Schaub, Sorber, and Taylor (1974) confirmed the effect of cations on the sorption of virus by turbidity. They postulated there might be two mechanisms associated with the sorption of virus by clay particles: one would be a clay-cation-virus bridge, and the other could be a mechanism similar to solids coagulation which is dependent upon zeta-potential. But regardless of the mechanism which accounts for virus survival, the absence of divalent cations tends to cause the virus to desorb. Wellings, Lewis, and Mountain (1974) studied the migration of virus by constructing wells to depths of 2, 5, 10, 15, 20, and 50 feet under a 10 acre sandy plot sprayed with raw sewage. They discovered that virus can survive sunlight and spraying and 20 feet of percolation into the ground and were able to isolate 5 polio 1 virus, 1 polio 2, and 1 Echo 7. Polio 1 was determined to be more stable and

long-lived than others in soil. Saturation apparently increases the solubility of the organic layer in the upper soil horizons and this causes desorption of the virus and furthermore prevents the virus from reabsorbing again so that virus "bursts" were found at depths of 10 feet and 20 feet. These authors also determined that standard chlorination practice does not provide a virus-free effluent from sewage treatment plants.

Methods for the identification of viruses in landfill leachates are applicable to this study. Sobsey et al (1974) have described the sorption of enteric viruses on particulate matter from landfill leachates and methods for desorption necessary for counting viruses. It is not permissible to add pathogens intentionally to a field site and then measure their survival. However, feces already contains pathogens and the virus experiments of Sobsey are merely the retrieval of viruses which are normally present in feces. Unfortunately, this is expensive work requiring primate kidney cell cultures.

A little work has been done for identifying limax amoebae from soils by the use of fluorescent antibody. But this method would be useful only to a small part of the U.S.

Stuart has found coliform bacteria surviving in animal droppings over the winter. Bacterial cultures intended for long preservation are freeze dried in an organic medium such as blood serum, skim milk or soil because drying in the presence of organic matter protects bacteria. Drying in feces would probably give some of the same protection although feces has not been tried for freeze drying. There are several papers claiming that the contribution of animal and human coliforms to the coliform count in water can be assessed through a comparison of fecal coliforms and fecal streptococci. However, Jackson (unpublished) using highly refined serological techniques was unable to verify this in work during research at Montana State University.

Leaching of nutrients and coliforms into recreational waters. The impact of recreational use upon water quality in the Boundary Waters Canoe area has been explored by King (1971) and King and Mace (1974) at six sites on Moose Lake and three sites on Isabella Lake and Isabella River. Sampling sites were close to the shore line at designated camping areas with six control sites at a radius of 200 feet from the campsite. Field measurements (conducted with a Hach Engineer's Field Laboratory) included: temperature, pH, dissolved oxygen, conductivity, turbidity, nitrite, nitrate, and kjeldahl nitrogen, and phosphate. They found recreational use has a small but adverse affect upon water quality and concluded that changes in sanitary facilities or user limitations may be needed because campsite coliform levels were found to be above the maximum considered safe for drinking water by the U.S. Public Health Service drinking water standards of 1962. Altogether, King and Mace accomplished a surprising amount of work with the limited resources of time and effort they were able to devote to the problem, but according to the paper of Kunkle and Meirnam (1968) conclusions based on their data alone would be questionable. The number and location of the control points did not allow a determination of how much pollution originated with man, and how much was caused by the toxic effects of the off-shore aquatic environment. To obtain data permitting unchallengable conclusions, it would be necessary to sample several points along the lake shore as well as a grid of control points from each lake shore sampling point extending both horizontally and vertically from the water's edge. Because water constitutes a debilitating environment, one would expect bacterial counts to be high at the shore, and if they are as high at sites not used for camping as they are at campsites, it could not be claimed that the increase of coliform is caused by man. Unfortunately, a clear determination would require a considerable effort, but on the other hand, anything less may to lead to erroneous conclusions.

CHAPTER 4
RESEARCH NEEDS

The studies described in Chapter 3 indicate a marked difference in fecal decomposition rates in a few different habitats within a small area (perhaps 3 miles long and ranging from 6300 feet to 8960 feet elevation). Moreover, these were only exploratory tests designed to test equipment and techniques more than to obtain hard data on decomposition. To provide reasonable data for input into U.S. Forest Service management decisions on Wilderness use, the scope, time frame, intensity, and range of conditions must be expanded considerably. Results to date show there will not be only one single answer to the question of how long a fecal sample must be buried before it is safe. There will instead be a range of answers depending upon the locality, climate, deposition conditions and other factors.

At the very least it is necessary to study a few widely different environments to determine the range of answers. Such a study can then be utilized to determine the number of intermediate habitats required for practical conclusions. Such a range can be found partly within Montana but will require in addition warmer, more xeric and also moister sites. Rapid decomposition will be found in sites where conditions produce a large and diverse soil microbial population with enough moisture to be active during most of the growing season. This will also be accompanied by a diverse population of small soil animals such as mites, collembolas, worms and insect larvae among others. Limited environments result particularly from a dearth of moisture, from an acid soil pH and from low temperatures. An extreme beyond the ordinary soil description is the site which consists only of rock, perhaps granite boulders such as are characteristics of most rock climbing areas. Sites with large,

active microbial and animal populations can be recognized at sight because of the types of vegetation which accompany them. Unfavorable sites can also be recognized by their characteristic vegetation.

A few extremes should be studied at first. However, it will be economical in any area to include a variety of other habitats which are encountered in reaching the desired test locations. For example, to reach sites above timberline it is usually necessary to pass through a succession of forest types as well as lowland and alpine meadows.

Table 3 gives an absolute minimum of sites to determine a range of decomposition rates.

TABLE 3

A MINIMUM LIST OF SITE TYPES TO DETERMINE A RANGE OF FECAL DECOMPOSITION

Type of Environment	Possible Locations
High elevation rock climbing area, no soil.	Montana, Bridger Mts. or Selway-Bitterroot.
Brown podzolic soils.*	Montana, Bridger Mts. or Selway-Bitterroot.
Moist, well drained mountain meadow with dense grass and sedge cover.	Montana, Bridger Mts. or Selway-Bitterroot.
Sandy soil, long season and good water supply.	Idaho. Salmon River sandbars.
Desert soil.	Undetermined southwest area.

*A true podzol would be more limiting but is apparently either not found in Wilderness or, is managed by a pit toilet system or would require a site in the northeast.

SURFACE DISPOSAL

The only surface disposal site was a single deposition of an aluminum sampler under Arctostaphylos. While the datum is limited it

supports a principle of soil microbiology that decomposition rates are strongly increased by contact with moist soil. A heavy rain might possibly wash the feces into the soil which would then provide the maximum possible treatment for surface deposits. But animal droppings have survived for over two seasons and hence human wastes could do the same. Meanwhile the potential for contact with other humans and for transfer by insect vectors remains a threat. It would be unwise to countenance surface deposition, but it must be studied at least to the extent of determining survival of bacteria and virus and the rates of biochemical decomposition.

The covering of feces by leaves or litter is inferior to surface disposal because it promotes drying and the preservation of fecal organisms in a viable state. Although our sample was largely decomposed, probably by fly larvae, the bacterial count remained high. Further investigation of a range of surface deposition conditions is needed.

Research is also needed to define the attenuation of bacteria and virus as rain and melting snow washes fecal substance down a slope. One form of land disposal (not yet widely practiced) for sewage effluents is overland runoff. It has the advantage of applicability where soils are too impervious to accept sufficient quantities by infiltration. Grass, litter, and surface organisms comprise a community that behaves somewhat like a trickling filter to give high BOD removals and reduce the numbers of bacteria. Experience with raw sewage is limited according to Thomas (1975), but some results have been reported by Thomas, Jackson, and Penrod (1974) although the results do not include attenuation of bacteria. Data developed in the future on bacterial destruction could, with caution, be applied to surface deposition and runoff. Experiments need to be established for several slopes and a variety of soils and litter to correlate bacterial travel with local conditions. As explained in Chapter 3 many organisms pathogenic to man are found in animal droppings. Hence, a knowledge of bacterial travel would be useful in locating (or

rerouting) trails near lakes and streams. On an exploratory basis, a limited amount of field work would result in a very large increase in knowledge concerning bacterial destruction in surface runoff.

SHALLOW BURIAL

Shallow burial is presently an often recommended practice. It preserves moisture, insulates against temperature extremes and, of course, provides intimate contact with a rich biota of competing soil organisms for rapid chemical and biological attack. Furthermore, it inhibits contact with most adult insect vectors (but not larval stages living in soil) and is a reasonable optimum of practicality and esthetics. Hence, it was the disposal method used almost exclusively in this study. But the variation in results with habitat and the persistence of fecal bacteria demonstrates the study should be greatly expanded because there is no information as yet on the time required for feces to become safe. The data do indicate that when the actual time is determined it will show some commonly accepted ideas to be grossly in error on the unsafe side.

Enough samples should be buried to furnish reliable statistical data and a variety of habitats should be chosen and clearly defined in ecological terms, for example the forest habitats of Montana as described by Pfister et al (1974). A minimum list was given in Table 3. The investigation should be extended on a large enough scale and with a sufficient time frame to establish the rate of decomposition of fecal material to the point of zero health hazard under a sufficient variety of habitats to encompass the ranges to be found in Wilderness areas.

The use of the sample holder developed in this study (Fig. 1) would allow the accumulation of a large amount of data in one summer if the sites were chosen early enough. However, coliforms are known to persist for more than a year and some monitoring would have to be extended through a third summer.

PIT TOILETS, LATRINES AND DEEP BURIAL

The conditions in old pit toilets are unknown, but if pathogenic bacteria can survive, a potential health hazard exists. A little field work would yield large returns with respect to knowledge about the physical and chemical conditions within the mass and the numbers of viable bacteria. It would require considerable laboratory work to identify types of bacteria and to determine whether Salmonella, Shigella and other pathogenic types can survive.

The leaching of bacteria from pit toilets or latrines in the BWCA for example could be determined with reasonable certainty in one summer. The sampling would have to be much more extensive than that reported by King and Mace (1974). If pit toilets are indeed leaching bacteria into the lakes, such an investigation would determine a correlation between health hazard and the location of latrines both inland and laterally from campsites. The work of King and Mace (1974) would be valuable in providing background and some framework for such further studies.

The leaching of nutrients into the BWCA lakes from latrines seems reasonably evident but whether this constitutes a health hazard depends upon point of view. Such nutrients are not themselves harmful to health in the concentrations reported. But if they trigger algal "blooms," high concentration of blue-green algae, unpleasant tastes and odors may occur. In severe circumstances, cattle have died from drinking water polluted by blue-green algae.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

Beginning in February 1974, the thrust of the project was directed toward Wilderness sanitation, and more specifically, public health hazards in the Wilderness as a function of man's activities. Published and unpublished literature has been extensively searched. Three Wilderness areas (Selway-Bitterroot, Salmon River Breaks, and Boundary Waters Canoe Area) were inspected by the investigators accompanied by U.S. Forest Service personnel. A limited pilot research program to evaluate burial, sampling, and transportation techniques and to gather limited data on decomposition of feces and survival of fecal bacteria has been made. Some apparatus has been developed and is currently in various stages of evaluation. Samplers to hold feces under controllable conditions in the field (Fig. 1) have been tested. An inexpensive and easily portable (even by backpacking) water bath incubator has been developed. Operating only with a fire and a dry battery, it will meet the stringent requirements of the APHA (1973) for temperature control ($44.5 \pm 0.2°C$), will not violate U.S. Forest Service regulations for Wilderness and will permit the counting of fecal coliform bacteria as accurately (and nearly as conveniently) in the field as in the laboratory.

The following conclusions and recommendations are based on all of the foregoing sources of information.

CONCLUSIONS

1. With a very low use rate, public health hazard in Wilderness is slight and almost independent of the number of users. With a heavy use rate, health hazards at established campgrounds could eventually

approach that now found in countries where defecation is practiced in open fields. At what is presently considered to be heavy use, or anticipated for the near future, health hazard from intestinally carried and transmitted diseases is highly dependent not only upon numbers of users but upon the method of disposal of feces. This makes the behavior of individuals a prime factor, so that the effectiveness of education, persuasion and enforcement becomes a major factor in management planning. The biological factors involved in the manner of human waste disposal are subject to experiment.

2. Current widespread beliefs about Wilderness sanitation regarding purity of drinking water, decomposition of human wastes, and survival of harmful microorganisms are often, and perhaps, usually grossly erroneous.

3. Decomposition of feces is a function of habitat, expressed as climate, soil type, vegetation, soil organisms and burial conditions. The optimum means for disposal of human wastes will differ with locale and the health hazard as related to decomposition time will vary with each type of habitat.

4. Feces attacked by soil organisms such as bacteria, fungi, insect larvae, worms, and a multitude of small soil animals such as arthropods may become esthetically innocuous within several days under extremely favorable conditions. But fecal organisms may well survive for one or two years. Pathogenic organisms ingested by larvae can survive in the insect and be deposited on food during the adult winged stage.

5. The survival time of coliform bacteria is much longer than the survival of detectable feces. The survival of pathogens (notably viruses and Shigella) is greater than coliforms in aquatic environments and might be greater under burial conditions as well.

6. There is an optimum burial depth which offers the best compromise of rapid degradation, destruction of pathogens, and sequestration from insect vectors. It will require careful, competent study to determine this optimum depth.

7. With adequate investigations, it will be possible to correlate esthetics (in a general way) and public health hazards (in relative terms) with different waste disposal methods and concentration of people. This will greatly assist Wilderness managers in determining the sustained use of a locale at a given statistical probability of developing a public health hazard.

8. Small and inexpensive changes in management options can result in greatly decreased public health hazard.

9. A few widely diverse study sites will economically yield a range of answers that will encompass the conditions in Wilderness areas. The difference between the extreme ranges can then be evaluated to determine whether intermediate conditions need study.

10. Delay between the sampling and the incubation of bacteria alters the results of bacterial counts in ways that are not accurately predictable. Delays of more than three or four hours invalidates significant results. In remote areas, accurate work must be done in the field.

11. MSU researchers have developed methods, techniques, and apparatus for both the field and laboratory experiments and tests significant for evaluating the degradation of feces, the survival of bacteria, and the evaluation of public health hazard.

RECOMMENDATIONS

1. The USDA Forest Service should fund a three-year study on surface, shallow burial and deep burial of feces at a minimum of three general regions: the Selway-Bitterroot Wilderness, Salmon Breaks Wilderness, and an area in the southwest to furnish a wide enough range of conditions. In addition, the Bridger Mountains furnishes a quick and convenient access for correlation of field and laboratory work that would be difficult to find elsewhere.

2. The limited work on wilderness contamination, largely confined to a few locations in Colorado, Wyoming, and Montana, should be extended to the regions above to furnish baseline data for aid in establishing health hazards. Such work can be carried on in conjunction with the work on human wastes at little added cost.

3. The USDA Forest Service should fund a two-year study on the Boundary Waters Canoe Area. These studies should be correlated with those begun by Mace and King (1974) but must be extended considerably in scope and a pristine, unused, but similar lake should be studied for baseline data. Such a location has been found.

4. A low-level but long-term study should be made on the decomposition rate of feces in the massive, deep burials of latrines and pit toilets. The investigation should include survival of coliforms, survival of pathogens, and (if the investigation shows the pit material does not decompose) means to start decomposition should be included.

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